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Differential Adaptation Strategies by Agro-Ecological Zones in African Livestock Management

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Abstract

This paper examines how farmers have adapted their livestock operation to the current climate in each agro-ecological zone in Africa. The authors examine how climate has affected the farmer's choice to raise livestock or not and the choice of animal species. To measure adaptation, the analysis regresses the farmer's choice on climate, soil, water flow, and socio-economic variables. The findings show that climate does in fact affect the farmer's decision about whether to raise livestock and the species. The paper also simulates how future climates may alter these decisions using forecasts from climate models and the estimated model. With a hot dry scenario, livestock ownership will increase slightly across all of Africa, but especially in West Africa and high elevation agro-ecological zones. Dairy cattle will decrease in semi-arid regions, sheep will increase in the lowlands, and chickens will increase at high elevations. With a mild and wet scenario, however, livestock adoption will fall dramatically in lowland and high latitude moist agro-ecological zones. Beef cattle will increase and sheep will fall in dry zones, dairy cattle will fall precipitously and goats will rise in moist zones, and chickens will increase at high elevations but fall at mid elevations. Livestock adaptations depend on the climate scenario and will vary across the landscape. Agro-ecological zones are a useful way to capture how these changes differ from place to place.

This paper—a product of the Sustainable Rural and Urban Development Team, Development Research Group—is part of a larger effort in the department to mainstream research on climate change. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The authors may be contacted at Niggol.seo@yale.edu, Robert.mendelsohn@yale.edu, Adinar@worldbank.org, and Pradeep.kurukulasuriya@undp.org.

Differential Adaptation Strategies by Agro-Ecological Zones in African Livestock Management[1]

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1. Introduction

Past studies in developing countries on climate change impacts on agriculture revealed that crops and especially grains are highly vulnerable to climate change (Rosenzweig and Parry 1994, McCarthy et al. 2001). The main reasons for such high vulnerabilities are that farmers in developing countries tend to be already located in a hot climate zone and that these farmers may have less capacity to cope with climate risks. Researchers have argued that farms in these areas should take adaptive measures in the coming decades to reduce potential climate change impacts (Burton 1997, Smith 1997, Leary 1999, Mendelsohn 2000; Smit et al. 2000, Smit and Pilifosova 2001). Empirical work has revealed that farmers can make several changes with relative ease to avoid large crop losses including switching crop types and irrigation (Kurukulasuriya and Mendelsohn 2007; 2008a, Seo and Mendelsohn 2008a). These adaptations are known to reduce but not eliminate the damages from climate change (Kurukulasuriya et al. 2006; Kurukulasuriya and Mendelsohn 2008b; Seo and Mendelsohn 2008b). Further, there are additional measures that would require public (government) coordination such as the development of irrigation potential and new breeds and varieties to cope with high temperatures. These adaptations describe long-run behavior and do not capture some of the potential problems associated with short-term adoption rates (Mendelsohn 2000; Kelly et al. 2005).

This paper examines long-term adaptations that farmers might make in their livestock choices in response to climate. We specifically examine whether adaptations vary across Agro-Ecological Zones (AEZs). Livestock is an important topic since livestock makes up over half of the total value of agricultural gross output in industrial countries, and about a third of the total in developing countries, and this latter share is rising rapidly (Nin, Ehui, and Benin 2007). Examining impacts across AEZs is important because there is strong evidence to suggest that adaptations vary across the landscape. Of course, climate is not the only variable that affects livestock choice. Farmers may invest in livestock as part of a tribal custom or tradition. They may use livestock as an investment device (wealth storage) in the absence of access to banking (Fafchamps et al. 1998).

Nonetheless, there is reason to believe that climate does affect livestock decisions. First, just looking at the distribution of livestock across the planet, different species are more suited for different climates. Second, livestock may be used as a form of insurance against crop loss in poor weather. Third, there is empirical evidence that climate affects livestock decisions in Latin America and Africa (Seo and Mendelsohn 2007; 2008c, 2008d). Warmer temperatures increase the probability farmers will own livestock. In addition, farmers change their portfolio of livestock species to match climate in their location. However, past livestock research did not consider different adaptation possibilities across AEZs.

Including information about AEZs helps in understanding the wide range of conditions that farmers are currently facing and why each farmer may wish to adapt in a different manner. The link between farm behavior and AEZs can also help extrapolate the results from a limited sample area to all of Africa. We make use of the existing classification of Agro-Ecological Zones in Africa by the Food and Agriculture Organization (FAO) and quantify adaptation strategies by AEZ. Of course, AEZs were not developed to measure livestock zones but rather crop zones. Although attempts to develop suitable classification zones for livestock have been undertaken, there is no final method that has yet been developed. We consequently rely on the AEZ classification system in this paper.

This paper examines two important farm decisions by livestock owners in an effort to adapt to climate change; livestock adoption and livestock species choice (Seo and Mendelsohn 2007; 2008c, 2008d). We run binomial and multinomial choice models to measure climate sensitivities of these choices and predict future choices based on the estimated parameters. We then examine the link between these adaptive behaviors and AEZs. We use this link to extrapolate behavior across Africa.

The paper proceeds as follows. The next section provides an economic theory of farm decisions of livestock adoption and livestock species choice. The third section is devoted to a detailed discussion of the data used in this study. Sections 4 and 5 present empirical results of the models and predictions for the future, respectively. The paper concludes with policy discussions and remaining issues.

2. Economic Theory

Although economic studies on climate change impacts on agriculture have focused on crops, most farmers in Africa manage livestock in addition to crops. Some farmers manage only crops, but other farmers add livestock to their portfolio for various reasons (Delgado 1999; Nin, Ehui, and Benin 2007). The first choice we examine is whether a farmer adopts livestock because of different climate conditions. First of all, we assume that farmers raise livestock if it is profitable to do so[6]. The second decision we examine is which livestock species to own. In Africa, there were five major animals raised as livestock: beef cattle, milk cattle, goats, sheep, and chickens. In our analysis, we will consider only these five alternative livestock species. We specifically examine the primary animal each farmer chooses, the animal that earns the greatest net revenue on each farm. In practice, farmers can actually choose more than one species at a time. For example, they can have beef cattle and chickens together. This paper assumes that the farmer chooses only one species, the one that is most profitable (Train 2003). We consequently focus only on the primary animal. In Africa, this seems reasonable, as about 90% of total net revenue from livestock management is from the primary animal. However, we have also explored examining all combinations of species and the results were quite similar, although not completely the same (Seo and Mendelsohn 2008c). With the species choice, we also assume that farmers choose the species that is most profitable. We hypothesize that the profitability and therefore livestock choices depend on the AEZ in which the farm is located.

Let the profit associated with livestock farming in a specific AEZ (w) be written in the following form:

$$\begin{aligned} \pi_{1w} &= V_1(Z_w) + \varepsilon_{1w} \quad \text{where } \mathrm{w} = 1,\dots,\mathrm{W}. \\ \pi_{0w} &= V_0(Z_w) + \varepsilon_{0w} \end{aligned} \tag{1}$$

where Z is a vector of exogenous characteristics of the farm and characteristics of the farmer. The subscript 1 refers to the ownership of livestock and 0 to no livestock. The subscript w refers to the AEZs. The farmer will choose to raise livestock if:

[6] The theory of profit maximization can be contested especially in Africa due to a fragile market system. Some also argued that livestock in Africa are kept for the store of wealth (Singh et al. 1986; De Janvry et al. 1991; Bardhan and Urdy 1999; Moll 2005). We made the following two adjustments to address the issues arising from special situations of African markets. First, we assume that if a farmer consumes his own product, it is valued at market price. Second, most farms depend on their own labor. Although it might be reasonable to value own labor by market wages, empirical examinations did not support any specific wage.

$$\pi_1^* > \pi_0^* \quad \text{or if } \varepsilon_0 - \varepsilon_1 < V_1(Z_w) - V_0(Z_w) \tag{2}$$

Assuming that the cumulative distribution of error term is a logistic function, the choice of whether or not to raise livestock can be estimated with a standard logit model.

The choice of which species to select is slightly more difficult because there are more choices. Let the profit from raising a specific livestock species (*j*) for a farm located in a specific AEZ (*w*) be written in the following form:

$$\pi_{jw} = V\ (Z_{jw}) + \varepsilon_{jw} \ \ \text{where j} = 1,\ldots,\text{J and w} = 1,\ldots,\text{W}. \tag{3}$$

The vector *Z* could include climate, soils, water availability, access variables, electricity provision, and education of the farmer. The subscript (*j*) refers to livestock species and (*w*) refers to the AEZ where the farm is located. Note that the farmer chooses animal (*j*) from the multiple alternatives, but he does not choose the AEZ (*w*). The profit function in equation 1 is composed of two components: the observable component *V* and an error term ε. The error term captures various errors such as measurement error, mis-specification of the model, or lack of appropriately available data.

The decision of a farmer who is located in AEZ (*w*) is to choose the one species that gives him the highest profit. Suppressing subscript w for convenience, the farmer will choose species (*j*) over all other farm types if:

$$\pi_j^* > \pi_k^* \text{ for } \forall \text{ k} \neq j. \quad [\text{or if } \varepsilon_k - \varepsilon_j < V\ (Z_j) - V\ (Z_k) \text{ for k} \neq j] \tag{4}$$

The probability P_j for livestock (*j*) to be chosen is then

$$P_j = \Pr[\varepsilon_k - \varepsilon_j < V_j - V_k] \ \forall \text{ k} \neq j \ \ \text{where } \text{V}_\text{j} = \text{V}\ (\text{Z}_\text{j}) \tag{5}$$

Assuming ε follows an identical and independent Type I Extreme Value distribution and the profit can be written linearly in the parameters, then the probability can be calculated by successive integration of the density function as

$$P_j = \frac{e^{Z_j \gamma_j + Z_j^2 \alpha_j}}{\sum_{k=1}^{J} e^{Z_k \gamma_k + Z_j^2 \alpha_k}} \tag{6}$$

which gives the probability of livestock (*j*) to be chosen among (*J*) animals (McFadden 1981).

For each AEZ *w*, the marginal effect of a change in climate on the probability an animal *j* is chosen can be obtained by differentiating Equation (6):

$$\frac{\partial P_{jw}}{\partial z_l} = P_{jw}[\gamma_{jl} + 2Z_{jwl}\alpha_{jl}] - \sum_{k=1}^{J} P_{kw}[\gamma_{kl} + 2Z_{kwl}\alpha_{kl}] \text{ for w} = 1,2,...,\text{W}. \tag{7}$$

The coefficients of the choice model γ and α are not dependent on the AEZ. However, the marginal impact of climate on the probability of selecting an animal depends on the climate conditions in each AEZ and so will vary by AEZ.

3. Description of the Data

The FAO has developed a typology of Agro-Ecological Zones as a mechanism to classify the growing potential of land (FAO 1978). The AEZs are defined using the length of the growing season. The growing season, in turn, is defined as the period where precipitation and stored soil moisture is greater than half of the evapotranspiration. The longer the growing season, the more crops can be planted (or in multiple seasons) and the higher are the yields (Fischer and van Velthuizen 1996; Vortman et al. 1999). FAO has classified land throughout Africa using this AEZ concept. Our study will use these FAO defined AEZ classifications.

The economic data for this study were collected by national teams as part of the GEF/World Bank project on climate change in Africa (Dinar et al 2008). The survey asked detailed questions on crops and livestock operation during the agricultural period of July 2002 to June 2003. The data were collected for each plot within a household and household level data were constructed from plot level data. In each country, districts were chosen to get a wide representation of farms across climate conditions in that country. The districts were not representative of the distribution of farms in each country as there are more farms in more productive locations. In each chosen district, a survey was conducted of randomly selected farms. The sampling was clustered in villages to reduce sampling cost. A total of 9597 surveys were administered across the 11 countries in the study: Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa, Zambia, and Zimbabwe.

Climate data were gathered from two sources. We relied on satellite observations for temperature and ground weather station observations for precipitation (Mendelsohn et al. 2007). The United States Department of Defense uses a set of polar orbiting satellites that pass above each location on earth between 6am and 6pm every day. These satellites are equipped with sensors that measure surface temperature by detecting microwaves that pass through clouds (Weng & Grody 1998, Basist et al. 2001). The precipitation data came from the Africa Rainfall and Temperature Evaluation System (ARTES) (World Bank 2003). This dataset, created by the National Oceanic and Atmospheric Association's Climate Prediction Center, is based on ground station measurements of precipitation.

The monthly data were organized into three month seasons. We define the winter in the northern hemisphere as the average of November, December and January. February, March and April are spring, May, June and July are summer, and August, September and October are fall. The seasons in the southern hemispheres are assumed to be 6 months apart from the northern hemisphere seasons. For example, the winter in the southern hemisphere is May, June and July (Kurukulasuriya et al. 2006).

Soil data were obtained from the Food and Agriculture Organization's digital soil map of the world (FAO 2003). The FAO data provide information about the major and minor soils in each location as well as slope and texture. Data concerning the hydrology were obtained from the results of an analysis of climate change impacts on African hydrology (Strzepek and McCluskey 2006). Using a hydrological model for Africa, the authors calculated flow and runoff for each district in the surveyed countries. Data on elevation at the centroid of each district were obtained from the United States Geological Survey (USGS 2004). The USGS data are derived from a global digital elevation model with a horizontal grid spacing of 30 arc seconds (approximately one kilometer).

4. Empirical Results

Table 1 presents the fraction of the farms that have adopted livestock for Africa as a whole and by each AEZ. For Africa as a whole, almost 80% of farms own livestock[7]. Table 2 presents the fraction of each livestock species chosen by farms with livestock. Across Africa, 32% of livestock farms chose chickens, 20% chose goats, 20% chose sheep, 20% chose dairy cattle, and 7% chose beef cattle. Within each species of animals, there are different breeds of that species. For example, beef cattle which are origin to India are believed to be more heat tolerant than the African native breeds of beef cattle (Oklahoma State University 2007). The current data, however, did not have information on the breeds within each species[8].

Tables 1 and 2 also reveal how these percentages vary by AEZ. Livestock are chosen by farms more often in high and mid elevation dry regions and less often in mid and high elevation humid forest and low elevation moist savannah. In Africa, livestock is more popular in drier locations. The choice of different livestock species also varies by AEZ. Farmers choose beef cattle more often in deserts but less often in high elevation dry regions. Dairy farms are chosen more often in desert, mid elevation, and high elevation regions and less often in low elevation regions. Sheep are chosen less often in high elevation and mid elevation regions that are moist and more often in low elevation regions. Farms in mid and high elevations are less likely to choose goats whereas farms in low elevations are more likely to pick goats. Chickens are chosen more often in wet places in low and mid elevation regions.

Figure 1 maps the AEZs across Africa. Agro-Ecological Zones are classified by climate, soils, and altitude. They are divided into five zones depending upon precipitation: semi-arid, dry savannah, moist savannah, sub-humid, and humid forest. Each of these five zones is again divided into three zones depending upon the elevation: lowland, mid-elevation, and high elevation. The remaining AEZ is desert. The Sahara desert occupies a vast amount of area in the north. There is also a desert in the south-western edge of the continent. South of the Sahara desert is semi-arid zones followed by dryland savannah, moist savannah, and humid forest. In central Africa around Cameroon, it is mostly humid forest in low elevation with high rainfall. This low-elevation humid forest turns

[7] It means the rest 20% of farms specialized in crops only.

[8] Researchers also found that the transfer of a new technology to Africa has been much slower than the rest of the developing countries (Evenson and Gollin 2003). Heat tolerant breeds of beef cattle largely had not been adopted by African farmers.

into mid-elevation and then into dry savannah as it stretches east toward Kenya. South of the humid forest is moist savannah followed by dry savannah. The AEZs of South Africa are mostly moist savannah in the east, dry savannah in the center, and desert in the west.

Because each AEZ faces a different climate and agricultural condition, we anticipate that farms in each AEZ adopt different agricultural practices. This is confirmed in Tables 1 and 2. We now wish to quantify this relationship more carefully with an empirical model. We first examine whether farms in each AEZ are more or less likely to adopt livestock operations. Table 3 presents the estimated results of a binary choice model of livestock adoption using a logit regression. The dummy variable for livestock ownership is run against linear and squared climate variables, climate interaction variables, soils, and socio-economic variables following the literature in this area (Mendelsohn et al. 1994, Adams et al. 1999). The regression uses summer and winter temperature and precipitation. The regression includes temperature and precipitation interaction terms for both summer and winter. Although models of crops have used all four seasons of the year, none of the livestock models estimated to date have found all four seasons to be significant in either South America or Africa (Seo and Mendelsohn 2007; 2008c; 2008d).

The regression confirms that the livestock ownership decision is highly dependent on the climate in which the farm is located. Both temperature and precipitation are significant especially in the summer. The summer temperature and precipitation interaction variable is negative and significant. This negative estimate of the summer interaction variable implies that farms are less likely to adopt livestock in warmer locations if the area is also wet. The interaction variables may be picking up problems with livestock diseases in hot wet locations (such as Trypanosomiasis (Nagana), Theileriasis (East Coast Fever), and Rift Valley Fever) (Ford and Katondo 1977; University of Georgia 2007).

Some of the control variables are also significant. When there is electricity in the farm, they are less likely to have livestock at all. Livestock is chosen more often in West Africa, the Sahel, and high elevation AEZs in which fewer farms have electricity compared to the other parts of Africa[9]. Most of the soil and flow variables are not significant. When water

[9] These results seem to be related to small livestock farms that own sheep, goats and chickens but do not have electricity. Farms with electricity have more often chosen cattle.

flow is high in a district, the district is more likely to have livestock, but the estimate is not significant. When the head of farm works at the farm, the farm is less likely to have livestock, but the estimate is not significant.

Due to its nonlinear functional form, it is difficult to interpret the estimated parameters in Table 3. We consequently calculate the marginal effect of temperature and precipitation on the probability to have livestock evaluated at the annual mean of each climate variable. The results presented in Table 4 reveal that, for Africa as a whole, livestock ownership increases with warming. However, as precipitation rises, farmers choose to own livestock less frequently. Both these results are reasonable given that a farmer's main choices are between crops and livestock. As it gets warmer, crops become much less profitable, making livestock more attractive. As it gets wetter, however, crops become much more productive, making livestock relatively less attractive. Livestock in Africa is also very susceptible to various livestock diseases which become prevalent in wet places (Ford and Katondo 1977, University of Georgia 2007).

To examine the choice of primary livestock species, we estimate a multinomial logit model. Table 5 shows a set of regressions, one for each animal, leaving out chickens. The independent variables include a set of climate variables, social variables, and own and cross prices. The coefficients on the seasonal climate variables reveal that species choice is highly sensitive to climate. Every species choice has at least some significant climate coefficients. Among the control variables, electricity and water availability are significant for cattle ownership. Farms with electricity are more likely to have dairy cattle, but less likely to have beef cattle. Electricity is needed in milking and cooling of milk. Farms in districts with more water flow are less likely to choose beef cattle but more likely to own dairy cattle. Beef cattle is concentrated in South Africa and high elevation farms in Kenya in which climate is dry and have lower water flow. Some but not all price variables are significant. The own price has a positive effect on choosing dairy cattle as expected but an unexpected negative effect on choosing beef cattle. The results reflect the fact that beef cattle can be sold only after 4-5 years of raising on the commons, but milk can be sold immediately. Hence higher milk price is incentive for the farmers whereas higher beef price is a disincentive to the farmers. Own price terms are not significant for goats and sheep, but cross price terms are highly significant for sheep ownership. When the prices of other animals are high, farmers tend to switch to other animals from sheep.

To understand the nonlinear climate coefficients, we calculate the marginal effects of temperature and precipitation on the selection of the above five species evaluated at the mean climate. Table 6 shows that farmers would change their portfolio of livestock as the current climate is disturbed. As temperature increases, farmers will switch from cattle and chickens to goats and sheep. Goats and sheep are more heat tolerant so they can endure the warmer temperatures[10]. Changing rainfall also shifts African farmer's choices. As rainfall increases, fewer farms choose dairy cattle and sheep while more farms raise goats and chickens[11].

One of the insights of this paper is that farmers should adapt to climate change differently depending upon the agricultural economic conditions of where the farm is located. This can be seen clearly from the Tables 1 and 2 in which farms in different agro-ecological zones show different preferences for livestock ownership and livestock species choice. Hence, as climate changes and agro-ecological conditions change for a farmer in a specific AEZ, the farmer is likely to change the portfolio of livestock.

Based on the parameter estimates in Table 3, we map in Figure 2 the current probability of owning livestock in each district. The leftmost figure in Figure 2 shows the current probability of owning livestock across Africa. The lowest livestock levels are in the moist lowland forests of central Africa. It is also clear that farms have less livestock in the desert areas of the Sahara and southwest and eastern Africa. Semi arid and savannah regions, however, have more livestock as can be seen in the Sahel and near Mozambique.

The current probability of owning dairy cattle and sheep are mapped in the leftmost figures in Figure 3 and Figure 4, respectively. The other livestock species are shown in the Appendix. Dairy cattle are chosen widely across Africa except in the Sahel and along the eastern edge of Africa. Note that dairy cattle are raised even in the driest and hottest places in Africa. In contrast, farmers avoid sheep in the dry and hot parts of Africa and also in lowland humid forests. Farmers are much more likely to select sheep in West Africa and mid elevation dry zones.

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[10] In contrast to beef cattle, goats and sheep provide a shorter cycle returns.

[11] Sheep are known to be much more vulnerable to the parasites that spread in wet conditions (Delgado 1999).

The maps for goats and chickens are placed in the Appendix. The maps for goats are similar to the maps for sheep. Goats are chosen more often in West Africa and in the eastern countries such as Kenya and Mozambique. However, in contrast to sheep, goats are owned by many farms in lowland humid zones around Cameroon. Chicken ownership resembles the results for dairy cattle. Chickens are owned widely across Africa, but are favored in wetter places below the Sahel. We do not present a beef cattle map. Beef cattle are highly concentrated in two places: South Africa and the highlands of East Africa.

5. Forecasting Livestock Adaptations

As climate change unfolds over the coming century, farmers are likely to adapt to the changes by adding or subtracting livestock operations and by switching livestock species to minimize the damage and take best advantage of new climate conditions. In this section, we provide an analysis of how farmers would make such changes in the next 100 years. We assume that the cross sectional patterns of behavior we observe today can be used to predict how farmers will adapt over the long run. In making these predictions, we assume that it is only climate that changes over time. Obviously, there will be many other changes as Africa develops including income, technology, and land use. Because we do not take these factors into account the projections should not be interpreted as predictions of what would happen in the future. These many factors need to be taken into account to predict future outcomes. The projections in this study are merely trying to see how farm choices might vary with climate. It is also important to understand that these projections are intended to represent long run adaptations, not changes that farmers make from day to day[12].

To introduce climate change, we examine a set of climate change scenarios predicted by Atmospheric-Oceanic Global Circulation Models (AOGCM's). We rely on two climate scenarios that bracket the range of outcomes predicted in the most recent IPCC (Intergovernmental Panel on Climate Change) report (IPCC 2007): CCC (Canadian

[12] Individual producer livestock holdings in Africa have been typically explained by a multi-year risk mitigation where the risks are driven by droughts and diseases (Delgado 1999). This analysis, however, examines livestock holdings as a long term adaptation to existing climate. Hence, if the climate in the year 2002 that our study is based on was substantially different from the normal climate, the estimates in the study suffer from the biases introduced by such discrepancies. However, there is no evidence of such a peculiarity in the year 2002 weather.

Climate Centre) (Boer et al. 2000) and PCM (Parallel Climate Model) (Washington et al. 2000).

Table 7 presents the mean temperature and rainfall predicted by the two models for the years 2020 and 2100. In Africa in 2100, PCM predicts a 2°C increase and CCC a 6°C increase in temperature. Rainfall predictions vary. PCM predicts a 10% increase in rainfall in Africa and CCC a 10% decrease by 2100. Even though the mean rainfall in Africa is predicted to increase/decrease depending on the scenario, there is also substantial variation in rainfall across countries. Examining the path of climate change over time reveals that temperatures are predicted to increase over time for all models. Precipitation predictions, however, vary across time for Africa: CCC predicts declining precipitation whereas PCM predicts a slight increase. However, it should be noted that predicted changes vary slightly for individual countries and regions.

5.1 Analysis for Africa

We simulate climate change impacts on the choice of livestock ownership and livestock species based on the parameter estimates in the previous section conditional on each of the above two climate scenarios. Table 8a indicates that more farmers in Africa will own livestock by 2020 under the hot CCC scenario and that much fewer farms will own livestock under the wet PCM scenario. Table 8b indicates that by 2100, the effects of each climate scenario will intensify. There will be a small reduction in livestock ownership with the PCM scenario and an increase under the CCC scenario. These results are due to a combination of seasonal changes in precipitation and temperature[13].

The results for each livestock species reveal that by 2020, beef cattle, dairy cattle, and chickens will begin to decline, but goats and sheep will increase. The results, however, depend on the climate scenarios. For example, although sheep selection will increase under the CCC scenario, it will decrease with the PCM scenario. Beef cattle will be chosen more often with the PCM. These trends intensify through 2100.

[13] These results may not hold if there will be a great deal of changes in the demand for livestock in the future (Delgado 1999). Population changes and urbanization in the coming decades will affect the overall results described in this paper. Although it is desirable to model these additional changes, it is difficult without a good general equilibrium model of the world economy which does not exist at the moment.

5.2 Analysis by Agro-Ecological Zones

The livestock choices in each AEZ are not identical to the average choices for the continent as shown in Tables 8a and 8b. For example, in 2100, continental livestock ownership is expected to decrease in the PCM scenario. Yet, in some AEZs, the probability to adopt livestock increases. For example, in the PCM scenario, livestock increases in the desert and lowland semi-arid regions. Although livestock ownership increases in every AEZ under the CCC 2100 scenario, ownership rises less in the lowland moist regions and much more in the mid and high elevation regions.

Table 8a also shows how the choice of each species would change by 2020. With the PCM scenario, chickens are chosen less often in most AEZs, but more often in the mid elevation semi-arid AEZ. Dairy cattle choice also decreases across Africa except for the desert areas. With the CCC scenario, goats are chosen more frequently across all the AEZs except for the lowland dry savannah and lowland semi-arid zones. Chickens also decrease overall, but they increase in the highland AEZs.

Table 8b shows the simulation results for 2100. Beef, dairy, and chickens had similar reactions across the two climate scenarios. Beef will likely fall in the desert but increase in the low and mid elevation moist regions. Dairy will fall in mid and high elevations but increase in low semi-arid regions. Chickens will increase in high elevation but decrease in low elevation regions. However, sheep and goats had different effects across AEZs depending on the climate scenario. In the PCM scenario, goats will increase in the high elevation regions. In the PCM scenario, goats will also increase in the mid elevation regions. Goats will fall in the mid elevation regions and in some lowland regions in the CCC scenario. Sheep will increase across the board in the CCC scenario. In the PCM scenario, sheep will fall in the high and mid elevation regions.

The change in the probability of livestock is presented in Figure 2 for the PCM (right figure) and CCC (center figure) scenarios. The PCM scenario shows that livestock ownership will decrease precipitously in lowland humid AEZs, mid elevation and high elevation AEZs. Only deserts will see an increase in livestock ownership in the PCM scenario. The CCC scenario shows that livestock ownership will increase across Africa except for the desert areas but it will increase more in the highland zones and West Africa.

The change in the probability of adopting dairy cattle and sheep are shown in Figures 3 and 4 respectively. The effect of the 2100 PCM scenario is shown in the right figure and the effect of the 2100 CCC scenario is shown in the middle figure. With the PCM scenario, dairy cattle ownership decreases in general but it increases in the areas close to the desert. The additional precipitation makes dairy cattle relatively more attractive in these dry areas. With the CCC scenario, dairy cattle ownership also decreases across the landscape, but especially in the high elevation AEZs.

Figure 4 shows the results for sheep. With the PCM scenario, sheep ownership decreases in desert, high elevation, and lowland humid regions. However, sheep ownership increases in West Africa and mid elevation areas in Southern Africa. With the CCC scenario, sheep ownership increases in all the AEZs, but especially in West Africa and mid elevation AEZs.

The figures for the distributions of goats and chickens in 2100 are shown in the Appendix. In general, goats and sheep show a similar change in their spatial distribution except that goats prefer wetter places while sheep prefer dryer places. Dairy cattle, beef cattle, and chickens follow a similar pattern as well in that they are all very vulnerable to warming. But chickens do well in the high elevation farms even if climate turns dry. When climate turns wet under PCM scenario, farms close to the deserts or in high mountains increase chicken ownership. Beef cattle ownership in the temperate regions of South Africa and Kenya will fall with warming. The effect is more severe, the warmer the temperature becomes.

6. Conclusion and Policy Implications

This paper examines how farmers currently adapt to the climate in each of their AEZs by choosing to raise livestock and choosing different species of livestock. In the first analysis, we ran a binary logit model of livestock adoption, and in the second analysis, we used a multinomial logit model across livestock species. The empirical estimates were used to compare climate change impacts in 2100 for each of the 16 AEZs of Africa.

Our results indicate that farmers will adopt more livestock as temperature increases. However, farmers decrease their ownership of livestock if rainfall increases. Livestock is chosen more often when climate is dry. They will also switch livestock species. As temperature rises, they tend to move away from beef cattle, dairy cattle, and chickens and towards goats and sheep. As precipitation increases, they tend to shift away from beef cattle, dairy cattle, and sheep towards goats and chickens.

These results, however, vary across Agro-Ecological Zones. Some adaptation strategies suggested by the Africa-wide results are not appropriate for a specific AEZ. To see the AEZ specific results, we simulated how climate change impacts would affect the above two choices for each AEZ. The results suggest that livestock ownership will increase across Africa except for the desert areas. The largest increase in livestock adoption will happen in the high elevation AEZs under the CCC scenario.

Livestock species choice will also differ by the AEZs. Dairy cattle, beef cattle, and chickens have similar responses across all two climate scenarios. Dairy cattle ownership will decrease across Africa, but especially in the high elevation AEZs. Beef cattle will fall in the desert but increase in low and mid elevation moist regions. Chickens will increase in high elevation regions but fall in low elevation regions. Sheep and goats, however, had different responses across the AEZs depending on the climate scenario. Under the CCC scenario, sheep ownership increases in all the AEZs, but especially in West Africa. Under the PCM scenario, desert, high elevation, and lowland humid regions all see a decrease of sheep ownership but sheep ownership increases in West Africa and mid elevation areas in the Southern Africa. In general, goats and sheep show a similar response to temperature changes, but goats prefer wetter places while sheep prefer drier places. Thus goats increase in low and mid elevation regions in the wet PCM scenario but decrease in these same regions in the CCC scenario.

In conclusion, farmers can make some adaptations to climate change by adding or removing livestock from their portfolio and by switching species. These adaptations vary across Agro-Ecological Zones. It is important that policies designed to facilitate adaptation avoid a uniform Africa-wide approach but rather be tailored to each Agro-Ecological Zone. Of course, there are many other determinants to livestock ownership and species choice that this study did not take into account. Future policies will have to take into account changes in global prices for livestock, and local changes in population, income, and development. This study provides just a preliminary perspective on what adaptations are appropriate for each future climate scenario.

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Table 1: Number of Livestock Farms by AEZs

AEZ	Description	Number	Percentage
Africa		8427	79.7
AEZ 1	Desert	959	82.1
AEZ 2	High elevation dry savanna	117	91.5
AEZ 3	High elevation humid forest	941	74.2
AEZ 4	High elevation moist savannah	362	80.1
AEZ 5	High elevation semi-arid	73	87.7
AEZ 6	High elevation sub-humid	800	82.8
AEZ 7	Lowland dry savannah	2798	79.6
AEZ 8	Lowland humid forest	1242	83.6
AEZ 9	Lowland moist Savannah	2152	73.1
AEZ 10	Lowland semi-arid	699	81.8
AEZ 11	Lowland sub-humid	1286	82.3
AEZ 12	Mid-elevation dry savannah	907	81.5
AEZ 13	Mid-elevation humid forest	984	75.2
AEZ 14	Mid-elevation moist savannah	2014	78.6
AEZ 15	Mid-elevation semi-arid	134	88.8
AEZ 16	Mid-elevation sub-humid	1039	79.2

Table 2: Number of Livestock Species by AEZ

(1) Africa

	Percentage
Africa	
Beef cattle	7.2
Dairy cattle	21.7
Goats	19.1
Sheep	20.0
Chickens	32.0

(2) By AEZs.

AEZ	Percentage	AEZ	Percentage
AEZ 1	Desert	AEZ 9	Lowland moist Savannah
Beef cattle	18.2	Beef cattle	4.1
Dairy cattle	51.6	Dairy cattle	16.3
Goats	4.5	Goats	22.9
Sheep	6.8	Sheep	23.2
Chickens	19.0	Chickens	33.5
AEZ 2	High elevation dry savanna	AEZ 10	Lowland semi-arid
Beef cattle	0.0	Beef cattle	5.3
Dairy cattle	53.9	Dairy cattle	40.2
Goats	2.6	Goats	18.7
Sheep	16.7	Sheep	20.4
Chickens	26.9	Chickens	15.4
AEZ 3	High elevation humid forest	AEZ 11	Lowland sub-humid
Beef cattle	4.0	Beef cattle	9.8
Dairy cattle	60.5	Dairy cattle	12.8
Goats	7.5	Goats	21.4
Sheep	11.7	Sheep	20.9
Chickens	16.4	Chickens	35.0
AEZ 4	High elevation moist savannah	AEZ 12	Mid-elevation dry savannah
Beef cattle	7.5	Beef cattle	11.5
Dairy cattle	43.7	Dairy cattle	33.5

Goats	6.0	Goats	9.4
Sheep	23.6	Sheep	14.2
Chickens	19.1	Chickens	31.6
AEZ 5	High elevation semi-arid	AEZ 13	Mid-elevation humid forest
Beef cattle	0.0	Beef cattle	4.5
Dairy cattle	67.4	Dairy cattle	47.0
Goats	14.3	Goats	12.1
Sheep	2.0	Sheep	12.1
Chickens	16.3	Chickens	24.4
AEZ 6	High elevation sub-humid	AEZ 14	Mid-elevation moist savannah
Beef cattle	7.9	Beef cattle	10.2
Dairy cattle	46.5	Dairy cattle	30.6
Goats	12.2	Goats	11.0
Sheep	14.3	Sheep	8.3
Chickens	19.2	Chickens	39.9
AEZ 7	Lowland dry savannah	AEZ 15	Mid-elevation semi-arid
Beef cattle	3.8	Beef cattle	5.1
Dairy cattle	16.5	Dairy cattle	47.5
Goats	22.7	Goats	14.1
Sheep	28.2	Sheep	16.2
Chickens	28.9	Chickens	17.2
AEZ 8	Lowland humid forest	AEZ 16	Mid-elevation sub-humid
Beef cattle	4.8	Beef cattle	5.9
Dairy cattle	7.5	Dairy cattle	51.2
Goats	28.0	Goats	10.9
Sheep	20.4	Sheep	13.2
Chickens	39.3	Chickens	18.8

Table 3: Logit Model of Livestock Adoption

Variable	Estimate	Chisq Statistic	P value
Intercept	-1.1147	0.95	0.33
Summer Temperature	0.1837	4.58	0.03
Summer Temperature^2	-0.0032	4.00	0.05
Summer Precipitation	0.0123	5.95	0.01
Summer Precipitation^2	-4.43E-06	0.37	0.54
Winter Temperature	-0.0249	0.13	0.72
Winter Temperature^2	0.00158	0.66	0.42
Winter Precipitation	0.0038	0.32	0.57
Winter Precipitation^2	-0.00006	8.35	0.00
Summer Temp * Prec	-0.00057	10.81	0.00
Winter Temp * Prec	-0.00002	0.00	0.96
Flow	0.00263	0.15	0.70
Head Farm	-0.0541	0.63	0.43
Electricity	-0.0836	4.93	0.03
Soil Ferralsols	1.196	0.45	0.50
Soil Luvisols	0.8625	3.04	0.08
Soil Vertisols	-0.4351	0.29	0.59

N=8113

Likelihood Ratio Test= 1640.70 (P value< 0.0001)

Table 4: Marginal Effects on Livestock Adoption (%)

	Africa	Desert	High dry savannah	High humid forest	High moist savannah	High semi-arid
Livestock	78.47	78.41	79.35	77.55	79.21	79.39
T	0.16	0.56	0.30	0.54	0.46	0.53
P	-0.063	-0.004	-0.017	-0.038	-0.004	-0.004

	High sub-humid	Low dry savannah	Low humid forest	Low moist savannah	Low semi-arid	Low sub-humid
Livestock	79.57	79.69	77.87	77.10	80.21	79.26
T	0.28	0.02	0.06	0.05	0.11	0.03
P	0.012	-0.070	-0.075	-0.119	-0.043	-0.055

	Mid dry savannah	Mid humid forest	Mid moist savannah	Mid semi-arid	Mid sub-humid
Livestock	78.49	77.76	77.26	79.19	78.52
T	0.42	0.19	0.40	0.37	0.26
P	-0.051	-0.040	-0.084	-0.014	-0.034

Table 5: Multinomial Logit Model of Livestock Species Choice

	Beef cattle		Dairy Cattle	
	Est	Chi-sq	Est	Chi-sq
Intercept	4.5920	1.35	24.0842	121.41
Summer Temperature	0.5554	3.32	-1.8232	128.46
Summer Temperature^2	-0.0099	3.02	0.0323	113.83
Summer Precipitation	0.0148	0.81	-0.0555	39.12
Summer Precipitation^2	0.0000	2.88	0.0001	33.27
Winter Temperature	-1.4005	88.81	0.2586	4.36
Winter Temperature^2	0.0320	49.72	-0.0101	8.73
Winter Precipitation	-0.0395	5.19	-0.1186	94.31
Winter Precipitation^2	-0.0001	0.75	-0.0002	23.16
Summer Temp * Prec	-0.0002	0.08	0.0013	15.52
Winter Temp * Prec	0.0030	10.16	0.0067	101.52
Flow	-0.0480	5.23	0.0353	7.70
Head Farm	-0.3760	2.60	0.0432	0.14
Electricity	-0.4324	17.83	0.1552	4.14
Beef price	-0.0020	4.80	-0.0008	1.58
Milk price	-0.0009	0.91	0.0013	4.34
Goat price	-0.0106	1.58	-0.0021	0.14
Sheep price	0.0090	2.26	0.0063	2.61

Note: N=4379, Likelihood Ratio Test=4497.60 (P value<0.0001)

Table 5: Continued.

	Goats		Sheep	
Intercept	Est	Chi-sq	Est	Chi-sq
Summer Temperature	-3.6110	1.78	4.2311	2.86
Summer Temperature^2	-0.1826	1.13	-0.1708	1.03
Summer Precipitation	0.0053	3.11	0.0023	0.60
Summer Precipitation^2	0.0058	0.30	-0.0009	0.01
Winter Temperature	0.0000	1.67	0.0000	0.28
Winter Temperature^2	0.3197	3.14	-0.2345	2.55
Winter Precipitation	-0.0058	1.69	0.0097	6.70
Winter Precipitation^2	-0.0207	2.23	-0.0212	1.48
Summer Temp * Prec	0.0001	4.41	0.0000	0.10
Winter Temp * Prec	-0.0003	0.67	-0.0002	0.26
Flow	0.0006	0.82	0.0004	0.22
Head Farm	-0.0107	0.20	-0.0322	2.27
Electricity	-0.1011	0.70	-0.0084	0.01
Beef price	-0.1184	2.72	-0.2674	14.98
Milk price	-0.0001	0.00	-0.0018	5.40
Goat price	-0.0014	2.54	-0.0037	15.69
Sheep price	0.0022	0.10	0.0064	0.95

Note: N=4379, Likelihood Ratio Test=4497.60 (P value<0.0001).

Table 6: Marginal Effects by AEZs (%)

	Africa	Desert	High dry savannah	High humid forest	High moist savannah	High semi-arid
Beef	3.07	4.48	1.97	1.47	3.81	1.80
T	-0.12	-1.46	0.04	0.31	-0.27	0.04
P	0.02	0.02	0.02	0.02	0.03	0.02
Dairy	24.11	59.99	21.47	48.78	38.73	30.27
T	-2.08	-1.27	-5.80	-6.92	-7.57	-8.07
P	-0.15	-0.11	-0.15	-0.46	-0.30	-0.24
Goats	17.16	4.29	13.14	9.98	9.48	9.54
T	1.13	0.83	1.72	1.88	1.93	1.91
P	0.13	0.01	0.11	0.20	0.12	0.06
Sheep	22.46	6.59	28.51	11.17	17.96	27.05
T	1.92	0.37	2.88	1.95	2.74	3.66
P	-0.13	-0.01	-0.13	-0.07	-0.07	-0.02
Chickens	33.20	24.64	34.91	28.61	30.02	31.33
T	-0.84	1.53	1.15	2.78	3.17	2.46
P	0.12	0.10	0.15	0.31	0.22	0.18

Table 6 continued.

	High sub-humid	Low dry savannah	Low humid forest	Low moist Savannah	Low semi-arid	Low sub-humid
Beef	3.95	2.06	2.48	2.78	1.60	3.16
T	-0.41	0.08	0.40	0.25	-0.03	0.48
P	0.02	0.02	0.02	0.03	0.01	0.03
Dairy	43.76	13.20	24.45	13.04	24.37	16.50
T	-8.55	-1.02	-2.52	-0.69	-1.17	-2.34
P	-0.26	-0.05	-0.18	-0.11	-0.06	-0.05
Goats	10.19	21.47	18.28	22.16	18.13	18.70
T	2.30	0.54	1.40	1.18	0.25	1.28
P	0.17	0.07	0.25	0.17	0.04	0.17
Sheep	14.23	34.38	16.09	25.29	30.51	22.86
T	2.58	2.78	1.36	1.98	2.50	1.99
P	-0.08	-0.11	-0.18	-0.19	-0.09	-0.24
Chicken	27.86	28.89	38.70	36.73	25.39	38.79
T	4.09	-2.38	-0.65	-2.72	-1.54	-1.41
P	0.15	0.07	0.09	0.10	0.10	0.09

Table 6 continued

	Mid dry savannah	Mid humid forest	Mid moist savannah	Mid semi-arid	Mid sub-humid
Beef cattle	3.75	1.67	5.31	7.75	2.86
T	-0.19	0.31	-0.32	-1.65	0.06
P	0.04	0.02	0.04	0.03	0.02
Dairy cattle	27.80	42.63	30.61	22.41	39.20
T	-4.17	-5.29	-3.45	-5.29	-6.37
P	-0.26	-0.43	-0.30	-0.17	-0.24
Goats	10.73	13.00	12.18	10.84	13.71
T	1.58	1.82	1.66	1.67	1.97
P	0.11	0.24	0.19	0.07	0.23
Sheep	18.23	10.71	12.00	26.56	14.03
T	2.12	1.35	1.34	3.13	2.15
P	-0.07	-0.11	-0.10	-0.07	-0.13
Chickens	39.48	31.98	39.89	32.45	30.21
T	0.67	1.80	0.77	2.14	2.19
P	0.19	0.28	0.17	0.14	0.13

Table 7: AOGCM Scenarios

	Current	2020	2100
Summer Temperature (°C)			
CCC	25.7	+1.4	+6.0
PCM	25.7	+0.7	+2.2
Winter Temperature (°C)			
CCC	22.4	+2.2	+7.3
PCM	22.4	+1.1	+3.1
Summer Rainfall (mm/month)			
CCC	149.8	-4.6	-33.7
PCM	149.8	-4.7	-4.7
Winter Rainfall (mm/month)			
CCC	12.8	+1.1	+3.5
PCM	12.8	+18.8	+21.6

Table 8a: Climate Change Impacts by AEZs by 2020 (%)

	Africa	Desert	High dry savannah	High humid forest	High moist savannah	High semi-arid
Livestock	78.47	78.41	79.35	77.55	79.21	79.39
CCC	0.98	0.73	0.99	1.45	1.12	1.20
PCM	-4.13	0.01	-2.64	-24.68	-10.16	-4.32
Beef cattle	3.92	4.48	1.97	1.47	3.81	1.80
CCC	-0.72	-2.32	+0.12	+0.46	-0.55	+0.06
PCM	+1.24	-0.60	+6.18	-0.03	+2.38	+6.02
Dairy cattle	24.11	59.99	21.47	48.78	38.73	30.27
CCC	-1.90	+1.24	-6.99	-6.46	-8.18	-9.67
PCM	-5.37	+2.15	-2.86	-31.61	-21.88	-9.76
Goats						
	17.16	4.29	13.14	9.98	9.48	9.54
CCC	-0.04	+0.79	+1.45	+1.28	+1.82	+2.25
PCM	+6.58	+1.48	+2.43	+42.57	+17.37	+5.00
Sheep						
	22.46	6.59	28.51	11.17	17.96	27.05
CCC	+5.76	+0.77	+5.20	+2.57	+4.14	+5.20
PCM	-0.84	-1.65	-15.67	-7.53	-10.41	-16.47
Chickens						
	33.20	24.64	34.91	28.61	30.02	31.33
CCC	-3.86	-0.48	+0.23	+2.14	+2.77	+2.16
PCM	-2.13	-1.37	+9.92	-3.40	+12.54	+15.20

Table 8a continued.

	High sub-humid	Low dry savannah	Low humid forest	Low moist savannah	Low semi-arid	Low sub-humid
Livestock	79.57	79.69	77.87	77.10	80.21	79.26
CCC	0.62	1.38	-0.60	1.85	1.13	0.12
PCM	-27.33	-1.06	-7.44	-3.87	-7.76	-9.09
Beef cattle	3.95	2.06	2.48	2.78	1.60	3.16
CCC	-0.55	+0.34	+1.18	0.44	0.46	1.72
PCM	+0.80	+2.47	+1.16	1.96	5.57	2.55
Dairy cattle	43.76	13.20	24.45	13.04	24.37	16.50
CCC	-10.64	-2.13	-2.61	-0.11	-1.39	-2.91
PCM	-33.26	-0.91	-7.41	-2.93	-0.93	-2.35
Goats						
	10.19	21.47	18.28	22.16	18.13	18.70
CCC	+2.19	-2.21	+3.11	-0.89	-2.56	1.34
PCM	+41.12	+0.54	+13.16	5.71	9.81	11.80
Sheep						
	14.23	34.38	16.09	25.29	30.51	22.86
CCC	+3.52	+9.95	+1.78	7.53	8.18	3.99
PCM	-10.51	+2.41	-4.63	0.80	-4.46	-5.82
Chickens						
	27.86	28.89	38.70	36.73	25.39	38.79
CCC	+5.47	-5.94	-3.46	-6.97	-4.68	-4.15
PCM	+1.85	-4.50	-2.28	-5.54	-9.99	-6.18

Table 8a continued.

	Mid dry savannah	Mid humid forest	Mid moist savannah	Mid semi-arid	Mid sub-humid
Livestock	78.49	77.76	77.26	79.19	78.52
CCC	1.62	0.67	1.94	0.99	0.73
PCM	-8.42	-20.51	-8.13	-3.29	-28.92
Beef cattle	3.75	1.67	5.31	7.75	2.86
CCC	-0.61	0.54	-1.11	-2.55	0.25
PCM	6.10	-0.11	3.84	5.86	2.68
Dairy cattle	27.80	42.63	30.61	22.41	39.20
CCC	-3.02	-4.21	-1.21	-6.08	-7.16
PCM	-7.20	-26.76	-11.70	-1.90	-28.18
Goats					
	10.73	13.00	12.18	10.84	13.71
CCC	1.30	1.30	0.61	1.78	1.36
PCM	10.56	38.58	13.03	3.06	42.25
Sheep					
	18.23	10.71	12.00	26.56	14.03
CCC	3.50	2.01	2.99	4.97	3.25
PCM	-11.27	-6.31	-5.34	-15.55	-10.29
Chickens					
	39.48	31.98	39.89	32.45	30.21
CCC	-1.18	0.37	-1.28	1.88	2.30
PCM	1.80	-5.41	0.16	8.53	-6.46

Table 8b: Climate Change Impacts by AEZs by 2100

	Africa	Desert	High dry savannah	High humid forest	High moist savannah	High semi-arid
Livestock	78.47	78.41	79.35	77.55	79.21	79.39
CCC	2.99	2.96	4.31	3.97	3.98	4.47
PCM	-3.51	1.52	-0.15	-21.29	-6.63	-1.02
Beef cattle	3.92	4.48	1.97	1.47	3.81	1.80
CCC	1.67	-3.89	0.16	2.57	-0.76	-0.08
PCM	2.39	-1.80	6.68	1.95	3.82	5.90
Dairy cattle	24.11	59.99	21.47	48.78	38.73	30.27
CCC	-5.76	-3.24	-16.93	-23.58	-25.36	-23.51
PCM	-5.57	-0.24	2.32	-33.95	-19.46	-0.31
Goats	17.16	4.29	13.14	9.98	9.48	9.54
CCC	-5.05	5.15	0.79	2.65	3.42	4.62
PCM	5.85	2.63	1.93	44.07	16.50	3.70
Sheep	22.46	6.59	28.51	11.17	17.96	27.05
CCC	22.10	3.00	27.99	17.34	23.80	25.71
PCM	3.11	-0.75	-12.26	-8.43	-8.82	-14.17
Chickens	33.20	24.64	34.91	28.61	30.02	31.33
CCC	-15.50	-1.04	-12.02	1.02	-1.10	-6.74
PCM	-6.90	0.16	1.32	-3.63	7.95	4.87

Table 8b continued.

	High sub-humid	Low dry savannah	Low humid forest	Low moist savannah	Low semi-arid	Low sub-humid
Livestock	79.57	79.69	77.87	77.10	80.21	79.26
CCC	2.70	3.07	0.62	4.70	2.58	1.76
PCM	-20.98	0.76	-11.84	-2.12	-4.31	-10.24
Beef	3.95	2.06	2.48	2.78	1.60	3.16
CCC	-0.66	2.98	12.86	4.61	1.92	14.94
PCM	2.37	3.45	5.13	5.38	6.29	8.37
Dairy	43.76	13.20	24.45	13.04	24.37	16.50
CCC	-28.81	-4.08	-0.01	-3.03	-2.50	-3.06
PCM	-29.68	-0.42	-8.63	-3.06	2.15	-0.48
Goats	10.19	21.47	18.28	22.16	18.13	18.70
CCC	3.68	-10.09	-4.96	-9.40	-8.78	-7.82
PCM	36.66	-3.58	17.19	2.83	2.75	10.77
Sheep	14.23	34.38	16.09	25.29	30.51	22.86
CCC	21.97	29.28	12.20	32.37	23.13	19.82
PCM	-10.06	10.72	-4.53	6.62	2.25	-5.22
Chickens	27.86	28.89	38.70	36.73	25.39	38.79
CCC	3.81	-18.10	-20.08	-24.55	-13.77	-23.88
PCM	0.71	-10.1	-9.16	-11.77	-13.44	-13.43

Table 8b continued.

	Mid dry savannah	Mid humid forest	Mid moist savannah	Mid semi-arid	Mid sub-humid
Livestock	78.49	77.76	77.26	79.19	78.52
CCC	4.72	2.26	5.09	3.97	3.11
PCM	-5.31	-19.53	-5.72	-0.66	-23.75
Beef	3.75	1.67	5.31	7.75	2.86
CCC	-0.16	4.25	-0.89	-5.47	2.41
PCM	5.55	1.69	5.22	3.68	7.08
Dairy	27.80	42.63	30.61	22.41	39.20
CCC	-14.14	-16.61	-12.50	-14.50	-21.81
PCM	-2.80	-30.35	-10.00	5.42	-25.12
Goats	10.73	13.00	12.18	10.84	13.71
CCC	4.23	0.76	3.20	3.13	0.27
PCM	9.71	42.04	11.10	2.10	36.32
Sheep	18.23	10.71	12.00	26.56	14.03
CCC	20.46	14.97	19.14	24.44	22.27
PCM	-10.59	-7.42	-5.04	-12.85	-10.41
Chickens	39.48	31.98	39.89	32.45	30.21
CCC	-10.39	-3.37	-8.96	-7.61	-3.14
PCM	-1.86	-5.95	-1.28	1.65	-7.87

Fig 1: Agro-Ecological Zones of Africa

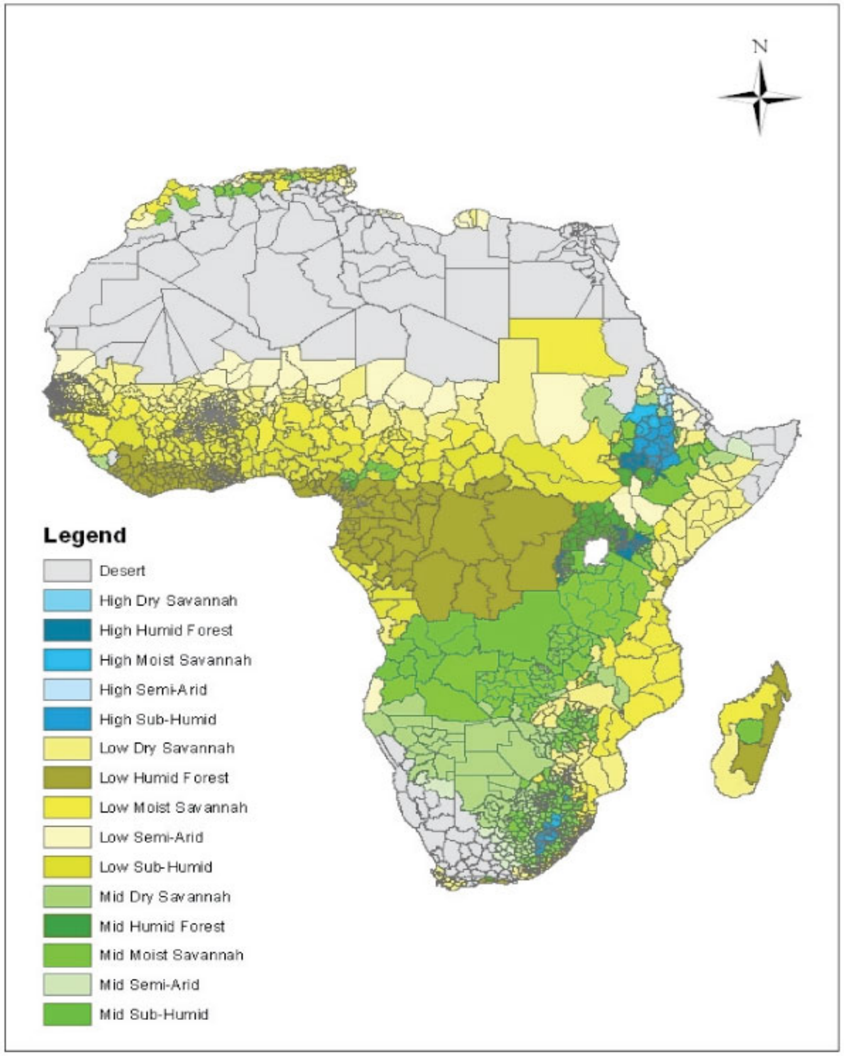


Figure 2: Estimated Probability to Own Livestock (Left), Change in Probability under CCC 2100 (Middle), and Change in Probability under PCM 2100 (Right).

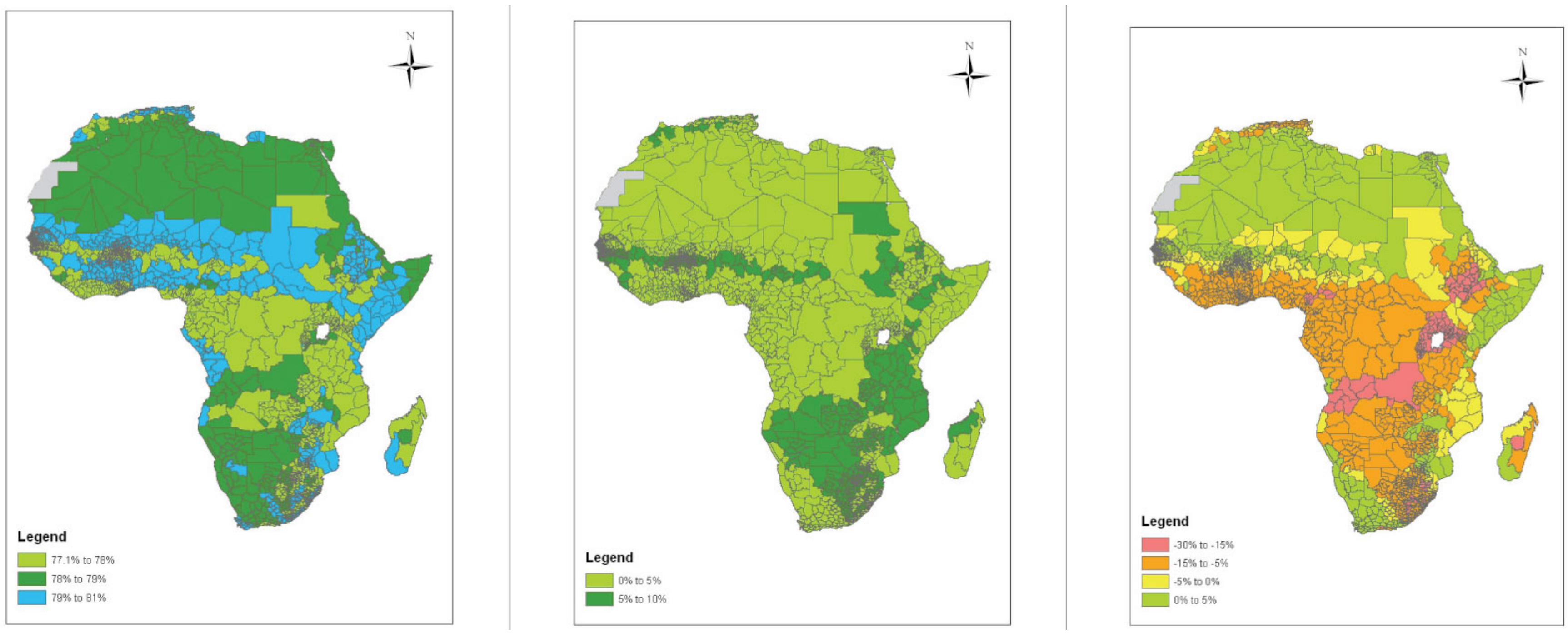


Figure 3: Estimated Probability to Choose Dairy Cattle (Left), Change in Probability under CCC 2100 (Middle), and Change in Probability under PCM 2100 (Right).

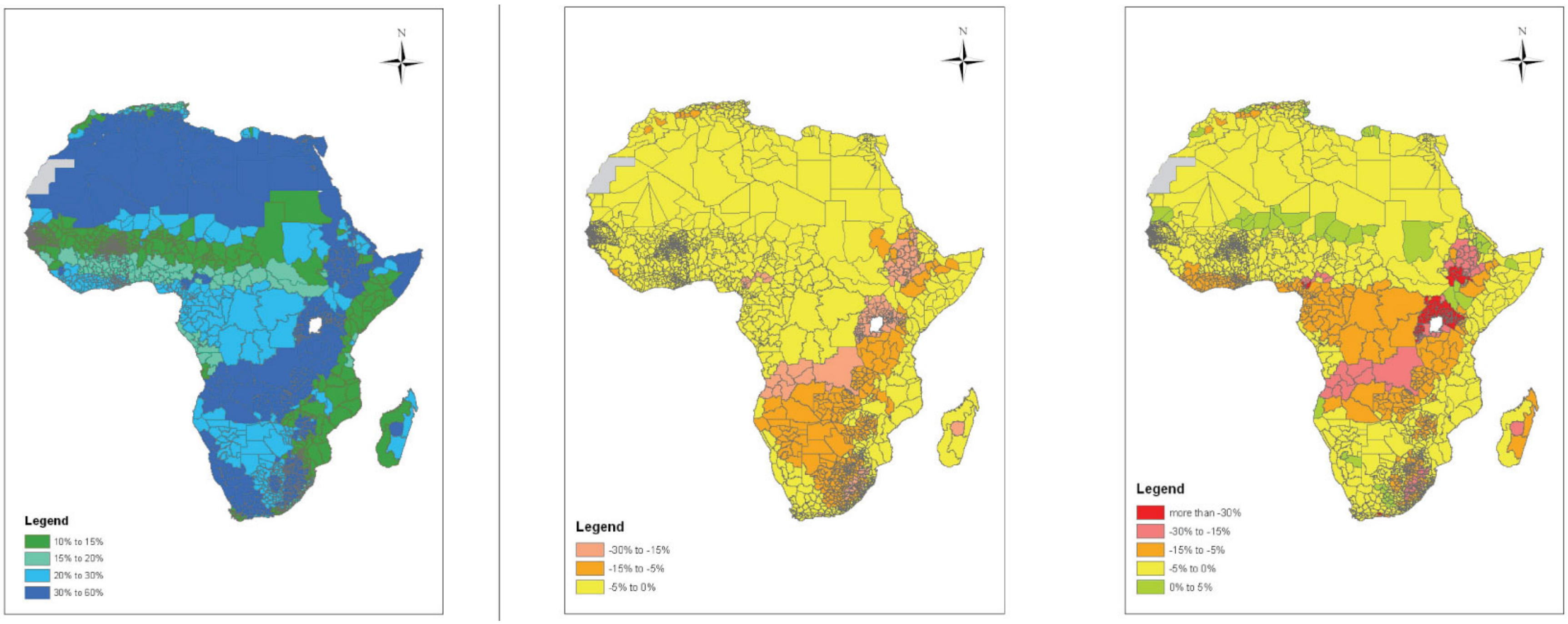
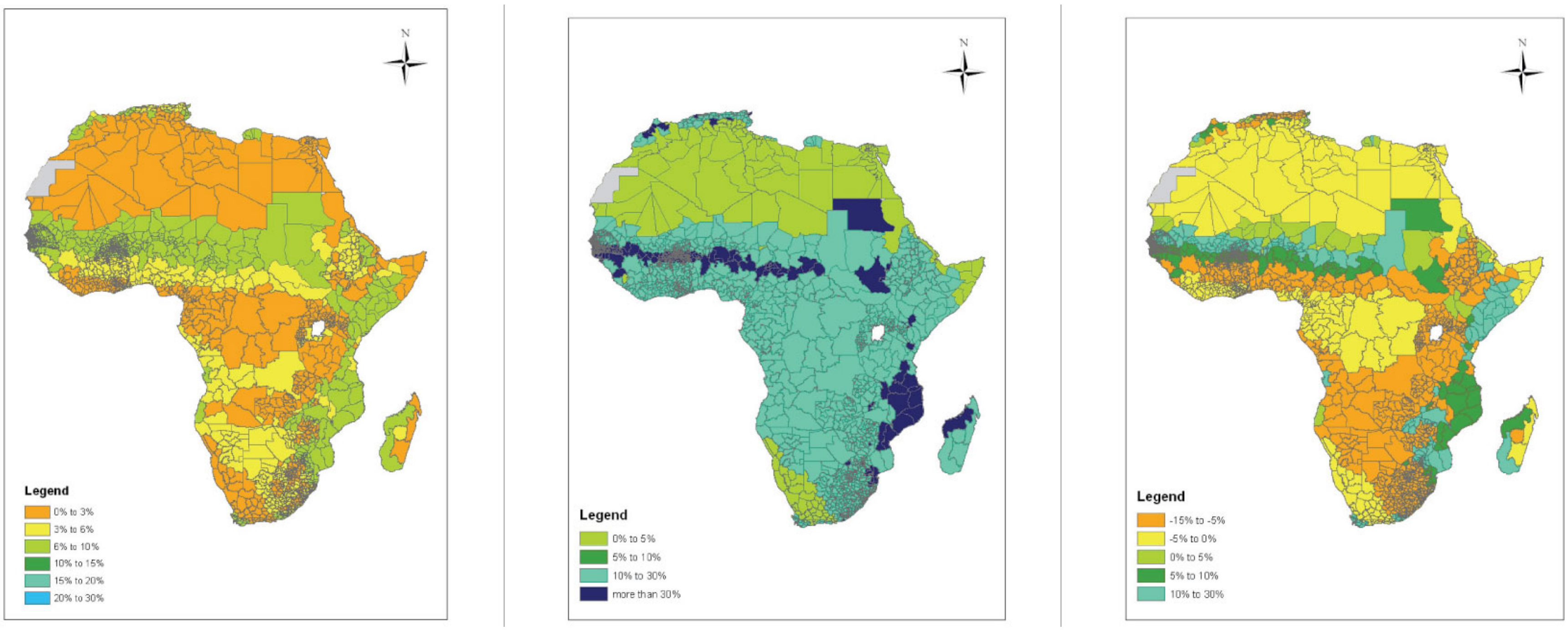
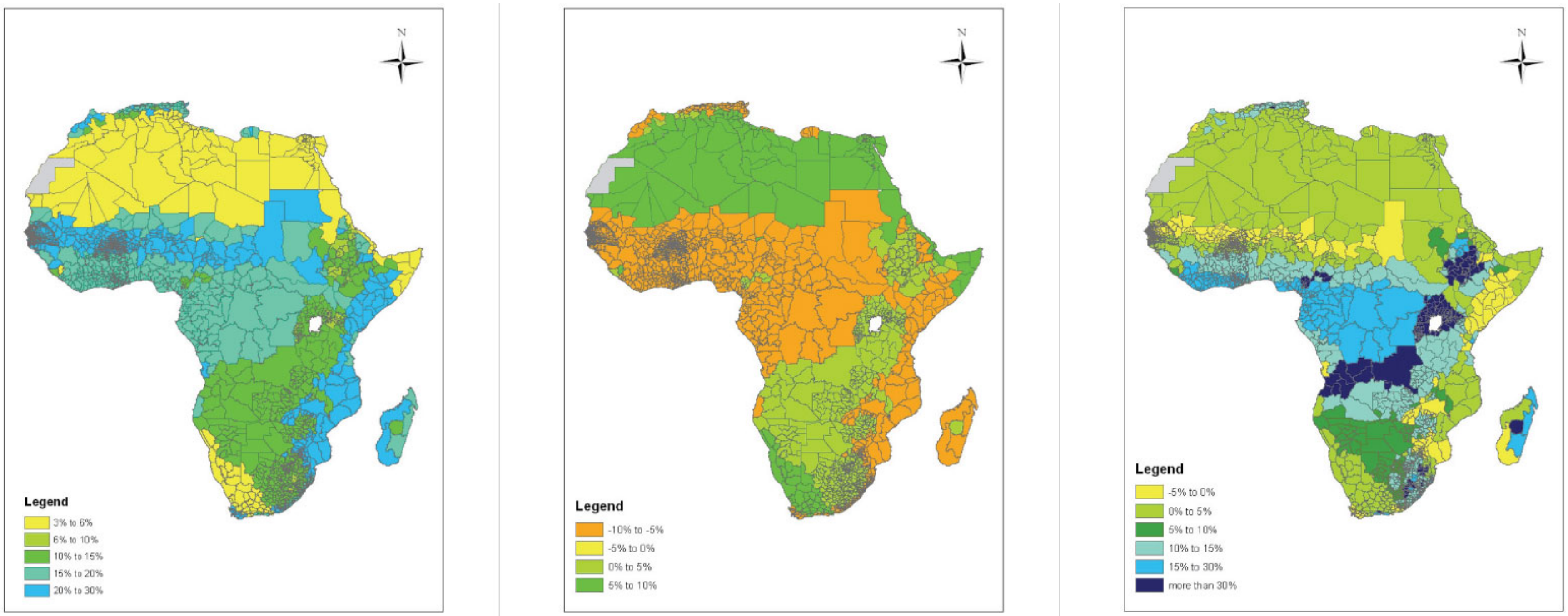


Figure 4: Estimated Probability to Choose Sheep (Left), Change in Probability under CCC 2100 (Middle), and Change in Probability under PCM 2100 (Right).



Appendix

Appendix 1: Estimated Probability to Choose Goats (Left), Change in Probability under CCC 2100 (Middle), and Change in Probability under PCM 2100 (Right).



Appendix 2: Estimated Probability to Choose Chickens (Left), Change in Probability under CCC 2100 (Middle), and Change in Probability under PCM 2100 (Right).